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Influence of Hub Ratio on Aerodynamic Noise of Radiator Fan

Bo Zhou[*1], Hui Wang[2], Xue Ding[3]

[1,2,3]School of Architecture & Civil Engineering, Shenyang University of Technology, China

No.111, Shenliao West Road, Economic & Technological Development Zone, Shenyang,110870, P.R. China

[*1]liguodapple@sina.com; [2]675947561@qq.com; [3]790916172@qq.com

Abstract

In order to discuss the influence of hub ratio on aerodynamic noise of a radiator fan, the simulation for radiator fan is conducted and the base model is also established in the text. The hub ratios that are 0.4, 0.45, 0.5 respectively are selected combining with the aerodynamic noise formula, And the figure of the relationship between hub radio and aerodynamic noise, and the changes of the flow and shaft power are confirmed by analyzing the three cases. It is determined that the level of aerodynamic noise can be lower with the increase of the hub ratio, and the noise reduction can be achieved by increasing the hub ratio.

Keywords

Fan; Noise Reduction; Hub Radio; Simulation; Aerodynamic Noise

Introduction

The hub ratio of the blade is crucial for radiator fans, and different hub ratios have great impacts on the noise of the fans. The small hub ratio causes a long blade and leads to a large area the blade accounts, also results in the increase of the rotation and the vortex noise. The big hub ratio causes the decrease of efficiency and the deterioration of performance. The change of hub ratio is tightly related to the flow, the hydrostatic, the power and the efficiency of fans, thus it is crucial to the general performance of fans. It also plays a significant role in the working process and causes the change of the level of aerodynamic noise. Therefore, selecting the appropriate hub ratio has an important significance on the control of aerodynamic noise.

The theoretical prediction methods of aerodynamic noise include the prediction in theoretical models and the prediction in semi-empirical formula [1]. Noise not only causes the environmental pollution, but also leads to the fatigue and damage to structures [2]. In previous studies for the hub ratio of radiator fans, the discussion of the impact on general performance was conducted by optimizing the hub ratio, but the impact on aerodynamic noise did not be discussed. In this text, the simulation of hub ratio for radiator fan is conducted detailed. And the flow, the power and other parameters as well as the final noise value are confirmed in every case by the simulation under different hub ratios. Thus the changes in aerodynamic noise are determined with the changing hub ratios, and the purpose of reducing noise can be achieved by increasing the hub ratio in a certain range.

FW-H Equation

The FW-H equation is made by rearranging the Navier-Stokes equation in hydromechanics in the form of the wave equation. The derivation experience is a complicated and rigorous mathematical process. Arbitrary motion of rotor blade is allowed in this equation, so the result is widely applicable. The FW-H equation is considered as the most general form of the Wright-Hill acoustic analogy. The method can also be applied to the prediction of the shedding noise in square cylinder vortex [3]. Assuming that the equation of permeable controlling is described as $f(x,t)=0$. Where the x is the space coordinate, the t is the time.

The FW-H equation [4] is:

$$\frac{1}{{c_0}^2}\frac{\partial^2}{\partial t^2}\left[pH(f)\right]-\nabla^2\left[pH(f)\right]=\frac{\partial}{\partial t}\left[\rho_0 v_i\frac{\partial f}{\partial x_i}\delta(f)\right]-\frac{\partial}{\partial x_i}\left[p_{ij}\frac{\partial f}{\partial x_j}\partial(f)\right]+\frac{\partial^2}{\partial x_i \partial x_j}\left[T_{ij}H(f)\right] \tag{1}$$

The result of FW-H equation in subsonic movement is: $$p'(x,t) = p'_L(x,t) + p'_T(x,t) \tag{2}$$

$$4\pi p'_T(x,t) = \frac{1}{c}\int_{f=0}\left[\frac{\rho_0(\dot{U}_n + U_{\dot{n}})}{r(1-M_r)^2}\right]_{ret} dS + \int_{f=0}\left[\frac{\rho_0 \nu_n (r\dot{M}_i\hat{r}_i + cM_r - cM^2)}{r^2(1-M_r)^3}\right]_{ret} dS \tag{3}$$

$$4\pi p'_L(x,t) = \frac{1}{c}\int_{f=0}\left[\frac{\dot{L}_i\hat{r}_i}{r(1-M_r)^2}\right]_{ret} dS + \int_{f=0}\left[\frac{L_r - L_i M_i}{r^2(1-M_r)^2}\right]_{ret} dS + \frac{1}{c}\int_{f=0}\left[\frac{L_r(r\dot{M}_i\dot{r}_i + cM_r - cM^2)}{r^2(1-M_r)^3}\right]_{ret} dS \tag{4}$$

Where

$$U_i = (1-\rho/\rho_0)V_i + \rho/\rho_0\mu_i U_n = U_i n_i \qquad L_i = \left[p_{ij} + \rho\mu_i(\mu_j - \upsilon_j)\right]n_j \tag{5}$$

It is indicated in the equation that the sound is assembled of three kinds of source distribution when a solid boundary exists in the sound field. One is the quadruple source of T_{ij} distributed in the outer surface of the solid; the other is the dipole source of $p_{ij}n_j$ distributed in the solid surface; the last one is the monopole source of $\rho_0\nu_n$ in the nature of the effect of volume moving, distributed in the solid surface.

Numerical Modelling

Modeling of Radiator Fan

In the beginning of CFD numerical simulation, the three-dimensional model is established firstly. The method can also be applied to calculate the loading of aerodynamic performance and the aerodynamic effect between fans [5]. Although the pre-processing software GAMBI has the functions of geometric modeling, the models are more complex and the requirement of surface modeling for modeling software is higher. The UG is used to establish the model of radiator fan in the text. The model fan has a 550mm diameter and five blades, and works in 2500r/min. The model figure of the radiator fan is showed in Fig.1.

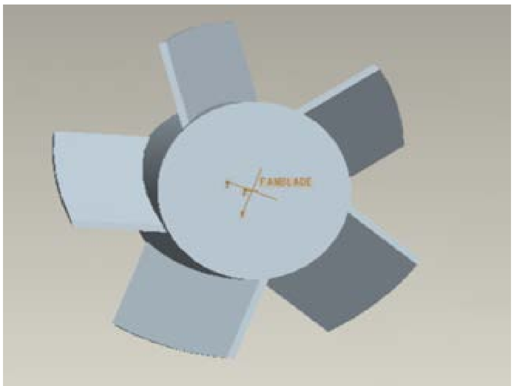


FIG.1 MODEL OF RADIATOR FAN

Model Meshing

1) The Establishment of Computational Domain

The establishment of computational domain is determined according to the physical problems of the object to be studied. The computational domain is showed in Fig.2 on the basis of numerical simulation for the noise of radiator fan.

2) Meshing of Computational Domain

The tetrahedral, hexahedral or other units of unstructured grids containing hexahedral or vertebral are divided in the geometry. For the complex geometries, the model is generally divided into multiple parts according to the shape. Respectively, the part is meshed in different gird form according to the rules of the shape in each

section. The figure of overall gird is showed in Fig.3.The table of grid nodes and the number of units is showed in Tab.1.

The model is based on the fan that has 5 blades and a 550mm diameter. The revolving speed is 2500r/min and the hub ratio is 0.4. Keeping the other factors constant with the hub ratio only increaseing, the models in hub ratio of 0.4, 0.45, 0.5 are confirmed. The simulation is conducted in the cases of different hub ratios, and the change is obviously indicated in the simulation.The blades are in the different levels of pressure when the changing hub ratio is conducted. And the figure of distribution of dynamic pressure is showed in Fig.4.

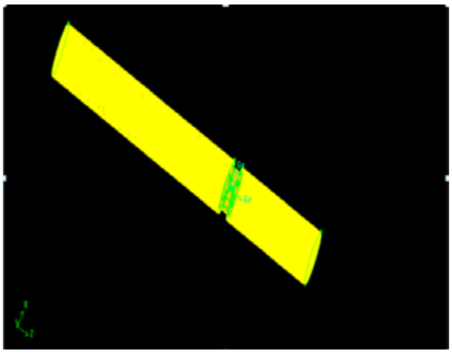


FIG.2 COMPUTATIONAL DOMAIN

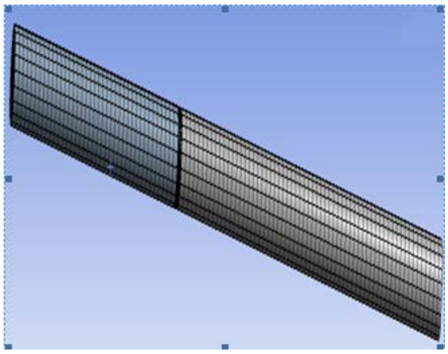


FIG.3 OVERALL GIRD

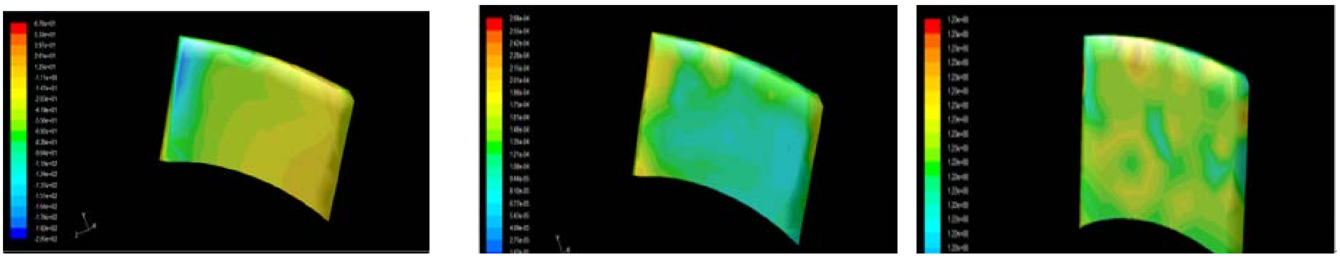
According to the simulation results, the data of flow and shaft power is showed in Tab.2.

TAB.1STATISTICS FOR GIRD NUMBERS OF THE COMPUTING DOMAIN

Area name	Grid format	Grid space	Grid cell number	Nodes
Import pipeline	Hex	3	48744	52483
Pipeline area	Hybrid	2	47623	16007
Fluid area	Hybrid	1	252688	51961
Export pipeline	Hex	3	97686	104222
		Total	446742	224678

TAB.2 DATA OF FLOW AND SHAFT POWER IN DIFFERENT HUB RATIO

Hub ratio	0.4	0.45	0.5
Flow	2.421	2.309	2.211
Shaft power	4.80	4.78	4.77



(A)HUB RATIO OF 0.4 (B) HUB RATIO OF 0.45 (C) HUB RATIO OF 0.5

FIG.4 DISTRIBUTION OF DYNAMIC PRESSURE

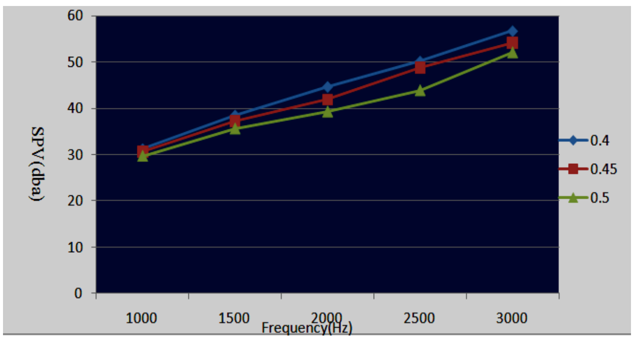


FIG.5 RELSTIONSHIP BETWEEN AERODYNAMIC NOISE AND FREQUENCY

According to the analysis of the FW-H equation, the figure of the relationship between aerodynamic noise and frequency in different hub ratio is showed in Fig.5

Analysis of Result

It can be seen from the Tab.2 that as the hub ratio continues to increase, the flow and shaft power have been decreasing, especially for the flow. As a result, the small hub ratio is good for improving the aerodynamic performance of the radiator fan. However, the small hub ratio causes the long blades and adds more difficulties to molding, At the same time, the long blades are bad for the strength. In Fig.4, it is obvious that when the hub ratio becomes larger, the noise is lower and it is the lowest when the hub ratio is 0.5.Therefore,the large hub ratio is in favor of noise reduction. But as for the overlarge hub ratio, the flow area is relatively small which results in the decrease of flow and shaft power, so under such a circumstance that the influence of radiator fan's work efficiency is small and the demand to the fan's aerodynamic performance is not high, it can be adopted that using the radiator fan with large hub ratio which is in favor of reducing noise.

Conclusions

In actual application of engineering, the temperature demanded by engine compartment and hood inside is very high, so the radiator fan is of great importance. The level of the aerodynamic noise needs to be controlled strictly for high efficiency. The parameters of blades, the structure of fans and the installation conditions should all be optimized. From the analog data in this paper, we can conclude that choosing a proper hub ratio is vital in construction. The reason of it is that within a certain rang, the increasing aerodynamic noise with the increasing hub ratio has an obvious decrease. The hub ratio is significant for the performance of the radaitor fans.

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